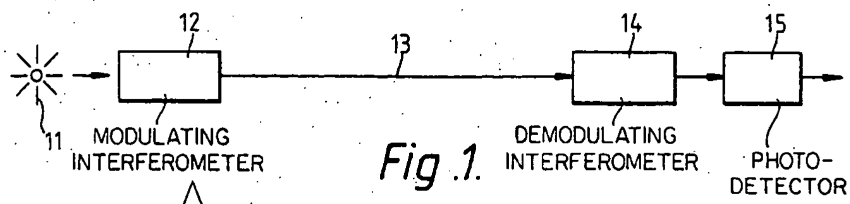


Fig.1.

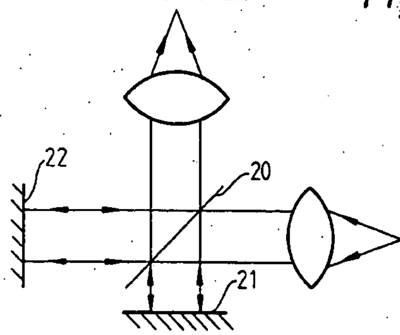


Fig.2a.

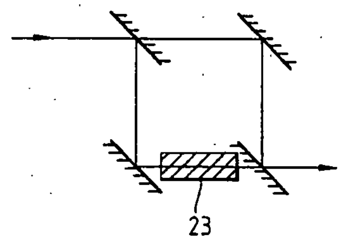


Fig.2b.

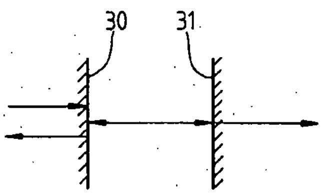


Fig.3a.

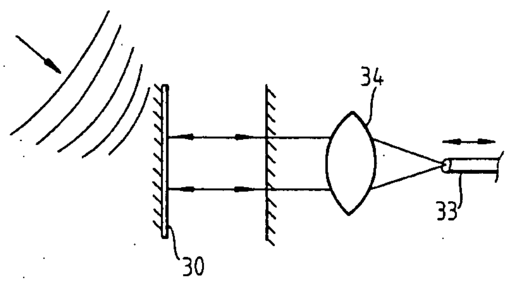


Fig.3b.

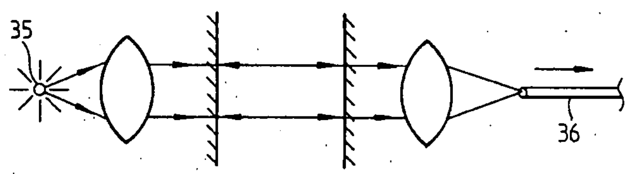


Fig.3c.

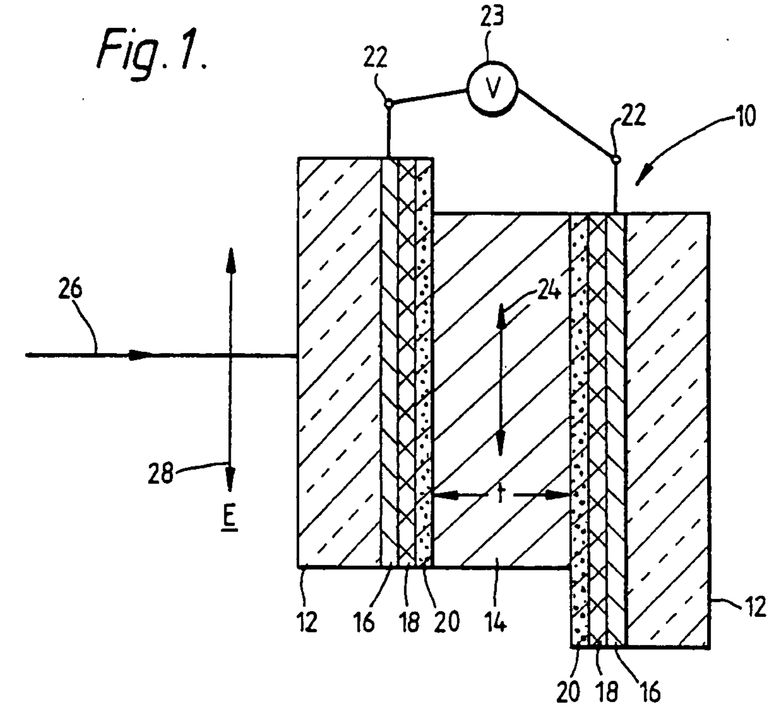
length is int rp s d in ne of th tw light paths in th int rf rometer.

(4) FIG. 3a illustrates th basic Fabry-P r t tal n structur . In id nt light enters a resonant cavity formed of two partially reflecting mirrors 30 and 31. Interference occurs between the mirrors 30 and 31 during multiple reflections. Some of the light is transmitted onwards through the mirror 31 while some of the light is returned towards the source through the mirror 30. Modulation can be effected by altering the resonant cavity length, e.g. by movement of one of the mirrors 30 and 31. FIG. 3b illustrates how one mirror 30 may be mounted on a transducer, e.g. a microphone diaphragm. The incident light is coupled into, and the modulated light coupled out of, the resonant cavity by an optical fiber 33 and a lens 34. FIG. 3c shows how an etalon can be interposed between a light source 35 and an optical fiber 36. Modulation is effected by altering the mirror spacing or the refractive index of the medium between two fixed mirrors 30 and 31.

(5) When information is impressed on the light by modulating the optical path difference in an interferometer, this has the effect of changing the spectrum of the transmitted light.

(6) The light output from the interferometer 12 is a comb spectrum.

Fig. 1.



23
22
V
22
10
26
24
28
E
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12
16
18
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14
12
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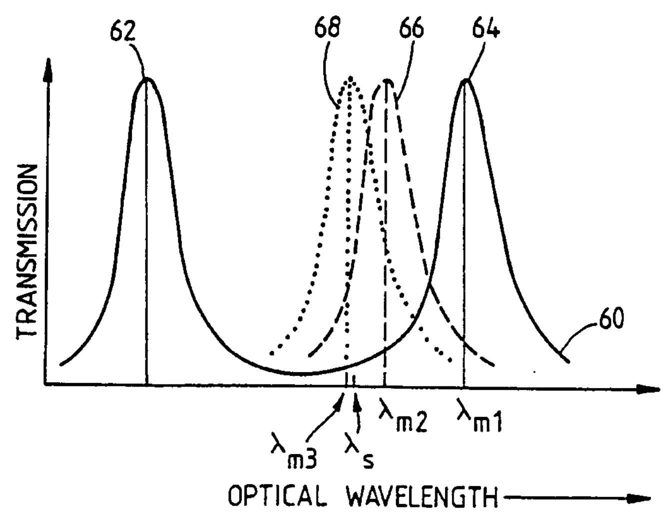
18
16

Fig. 12.



62
68
66
64
TRANSMISSION
60
λ_{m3}
λ_s
λ_{m2}
λ_{m1}
OPTICAL WAVELENGTH

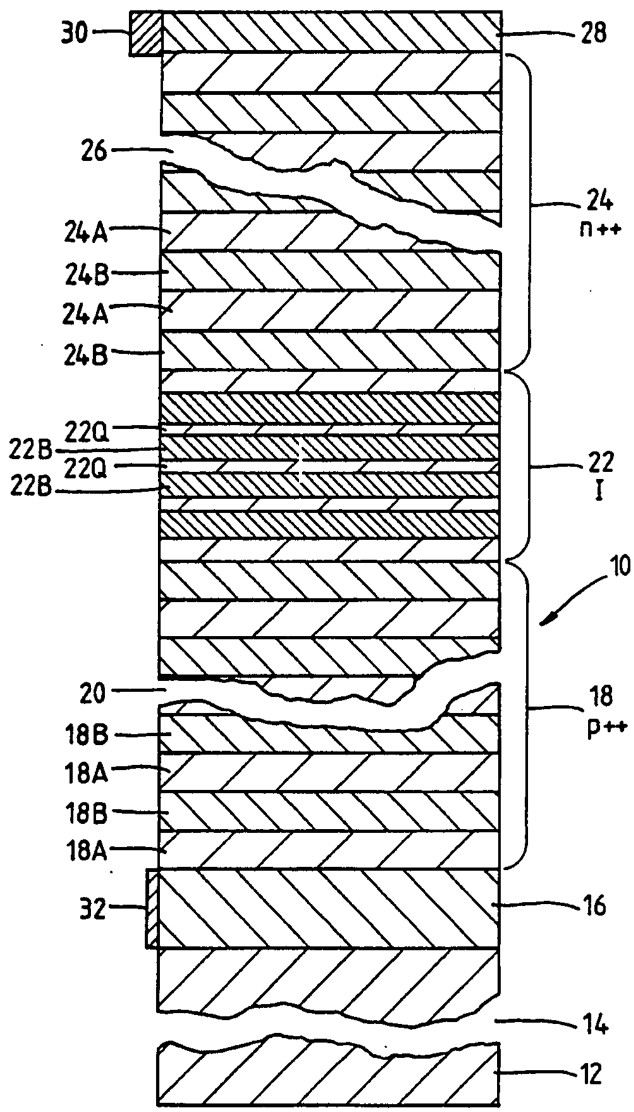
uantum w ll stru tur s.

(1) Ref rring to FIG. 1, th r is shown a sectional vi w f an pti ally bistable l ctro-optic Fabry-P r t tal n 10 f rming part of an ptically bistable device of the invention. The etalon 10 comprises two glass plates 12 acting as cell walls for a liquid crystal maerial (LCM) layer 14 contained therebetween. The glass plates 12 have respective internal wall coating layers of indium tin oxide (ITO) 16, evaporated silver 18 20 nm in thickness and evaporated silicon oxide 20 (SiO). These layers are successively disposed so that the structure is glass/ITO/Ag/SiO/liquid crystal, ie 12/16/18/20/14 from the left of the etalon 10 or the reverse of this order from the right. The ITO layers 16 are electrodes having electrical bias connections 22 connected to a variable voltage source 23.

(2) The liquid crystal material of layer 14 is referred to as 3/5/7 PCH, and consists of a three component mixture of materials each of the cyano-phenyl-cyclohexane-alkyl variety. The components differ only in that their alkyl chain lengths vary. Their structure is: ##STR1## where the components have respective values of n of 3, 5 and 7. The mixture proportions are 30% n=3, 40% n=5 and 30% n=7.

(3) The LCM layer 14 is 10 microns

Fig.1.


30
28
26
24
n++
24A
24B
24A
24B
22Q
22B
22Q
22B
22
I
10
20
18
p++
18B
18A
18B
18A
32
16
14
12

gi n 22 of intrinsic conductivity. V ry littl of the appli d bias pot ntial app ars across th mirr rs 18 and 24 b cause th y ar h avily dop d and highly c nducting.

(7) The Fabry-Perot etalon defined by the mirrors 18 and 24 and central region 22 is designed in the absence of bias voltage on contacts 30 and 32 to transmit light at a wavelength of 840 nm, and to reflect other wavelengths within the wavelength band for which the mirrors are reflecting. As is well known, a dielectric stack mirror of alternating refractive index only reflects in a wavelength band. The QW layers 22Q have a first confined hole to electron transition which is an energy of about 1.55 eV, equal to the photon energy at the 850 nm Fabry-Perot transmission wavelength.

(8) The transmission wavelength of the modulator 10 is determined by the refractive index of the central region 22, provided of course that the mirrors of 18 and 24 are reflecting at this wavelength. This is because the refractive index of the central region 22 determines the optical path length and phase difference between successive reflections from one mirror reaching the other. The condition for constructive interference and therefore transmission is that the path difference be an integral number of wavelengths, and wavelength in a material is inversely proportional to the material's refractive index. This is of course well known in optics. However, the real part of the refractive index of any semiconductor material at or near a resonance or absorption band varies with applied electric field. The electric field dependence is a very weak effect, the obtainable variation in refractive index being less than 1% for practical values of electric field. However, since the central region 22 is within a Fabry Perot etalon, even a small change in its refractive index is sufficient to move the etalon's transmission wavelength. Accordingly, varying the reverse bias voltage applied across electrical contacts 30 and 32 varies the electric field in central region 22 and hence also its refractive index. This alters the Fabry-Perot transmission wavelength. If the modulator 10 is illuminated with monochromatic light of the zero bias transmission wavelength, applying a bias voltage reduces the transmitted intensity and electrical modulation of light intensity is achieved.

(9) Referring now to FIG. 2, there is shown a graphical illustration of the effect of varying the refractive index of the central region of a Fabry-Perot talon. FIG. 2 show two plots 40a and 40b of etalon reflectance against wavelength in nm, reflectance being plotted on a scale of 0 to 1.0 equivalent to 0 to 100%. The graphs were calculated for idealised structures similar to the FIG. 1 modulator form, in which the equivalents of central regio

United States Patent [19]

Stone

[11] **Patent Number: 4,830,451**

[45] **Date of Patent: May 16, 1989**

[54] **TECHNIQUE AND APPARATUS FOR FABRICATING A FIBER FABRY-PEROT ETALON**

[75] Inventor: **Julian Stone**, Rumson, N.J.

[73] Assignees: **American Telephone and Telegraph Company**, New York, N.Y.; **AT&T Bell Laboratories**, Murray Hill, N.J.

[21] Appl. No.: **836,497**

[22] Filed: **Mar. 5, 1986**

[51] **Int. Cl.⁴** **G02F 1/21**

[52] **U.S. Cl.** **350/96.15**; 350/96.29; 356/352

[58] **Field of Search** 350/96.15, 96.29, 96.18, 350/96.13, 354, 355; 356/352, 345

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Electronics Letters, vol. 21, No. 11, May 23, 1985, "Optical Fibre Fabry-Perot Interferometer with Finesse of 300", J. Stone, pp. 504-505.

Primary Examiner—John D. Lee

Attorney, Agent, or Firm—Samuel H. Dworetsky

[57] **ABSTRACT**

A practical, manufacturable Fabry-Perot etalon and method for fabricating the same is disclosed. The plastic coating material is removed from the ends of a predetermined length of single mode fiber. A small area of the glass fiber is exposed by scraping away the coating near the center of the fiber on one side, and the fiber is then broken at this point forming a small gap. The remaining coating holds the broken fiber together and automatically matches the pieces in alignment. Mirrors of desired relfectivity are applied to the polished fiber ends, either by gluing on discrete mirrors or by applying multilayer dielectric coatings. The fiber/mirror structure is mounted onto a piezoelectric substrate. A voltage is applied to the piezoelectric substrate, causing longitudinal expansion of the fiber gap and providing the scanning means to obtain a spectrum of resonant wavelengths.

11 Claims, 2 Drawing Sheets

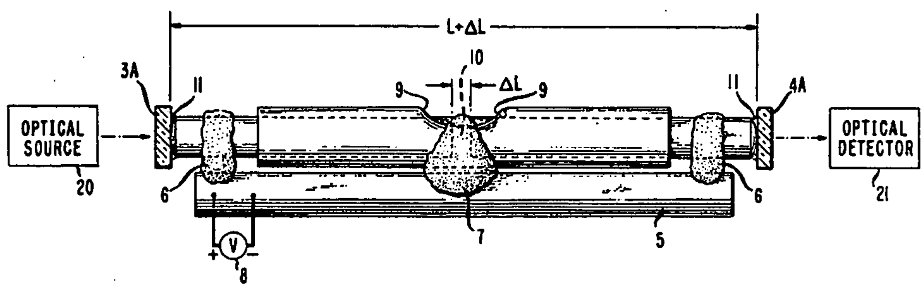


FIG. 1

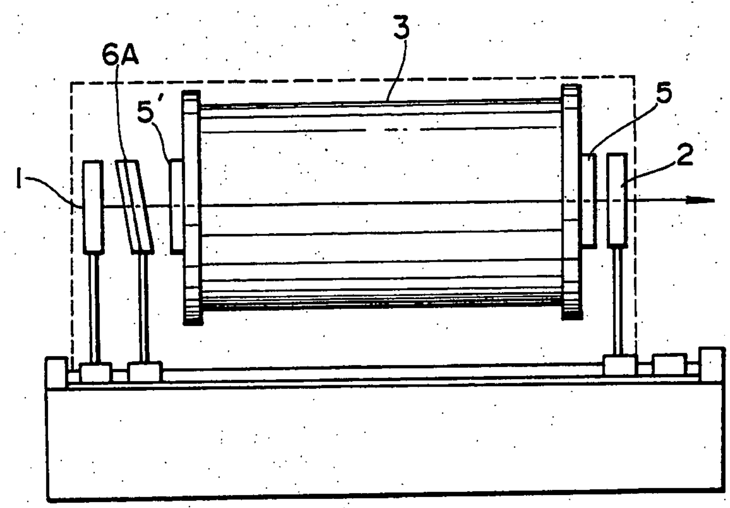
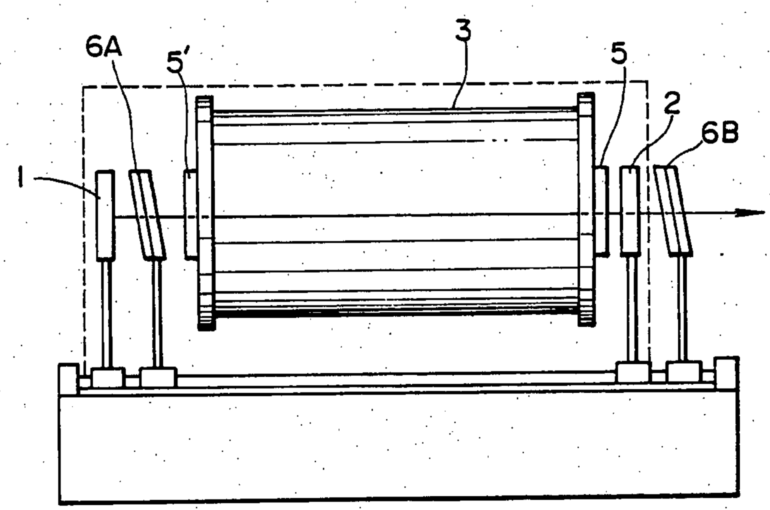


FIG. 2



h las r devic s ar not suitabl for us in th r duc d
proj ction.

(6) Let us d scrib the air gap etalon 6A acting as wav l ngth s lecting means. Since the etalon 6A is disposed between the total reflection mirror 1 and the chamber 3 an extremely high wavelength selection effect can be obtained

as will be described later. When the etalon is disposed at the position shown in FIG. 1. The light generated in chamber 3 impinges upon the total reflection mirror after it has passed through the etalon 6A. The light reflected by the mirror 1 passes again the etalon 6A and is then amplified. In other words, the light is subjected to the wavelength selection operation of the etalon during its go and return passes. For this reason, in this embodiment, laser light having an extremely narrow spectrum light can be produced.

(7) Where the etalon 6A is disposed between the output mirror 2 and the chamber 3, a strong wavelength selecting function described above can not be expected so that it becomes impossible to reduce the spectrum line width.

(8) FIG. 2 shows a modified embodiment of this invention in which in addition to the etalon 6A described above, another etalon 6B is disposed on the outside of the cavity of the excimer laser device. With this modification, the laser light produced by the

United States Patent [19]

Yasuda et al.

[11] Patent Number: 4,947,398

[45] Date of Patent: Aug. 7, 1990

[54] LASER DEVICE WITH WAVELENGTH STABILIZATION CONTROL AND METHOD OF OPERATING THE SAME

[75] Inventors: Kenichi Yasuda; Hitoshi Wakata; Hajime Nakatani, all of Amagasaki, Japan

[73] Assignee: Mitsubishi Denki Kabushiki Kaisha, Japan

[21] Appl. No.: 372,834

[22] Filed: Jun. 29, 1989

[30] Foreign Application Priority Data

Oct. 20, 1988	[JP]	Japan	63-262877
Jan. 13, 1989	[JP]	Japan	1-4767
Feb. 14, 1989	[JP]	Japan	1-32768

[51] Int. Cl.[5] H01S 3/10

[52] U.S. Cl. 372/29; 372/32

[58] Field of Search 372/29, 31, 20, 32, 372/92, 98

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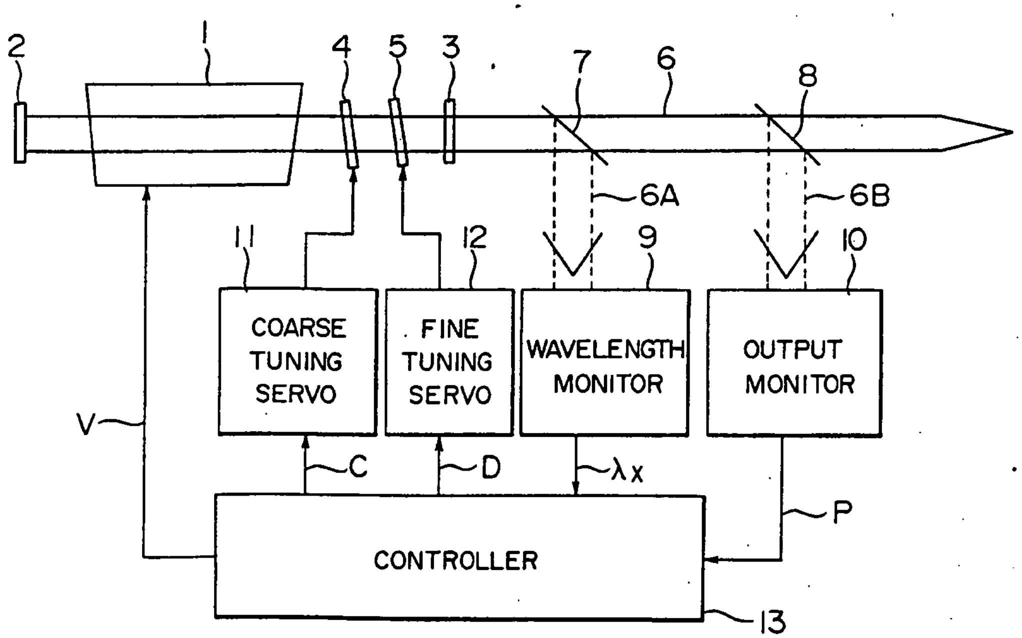
Primary Examiner—James W. Davie

Attorney, Agent, or Firm—Leydig, Voit & Mayer

[57] ABSTRACT

Methods of controlling the wavelength and output power of a laser device with two intracavity etalons are disclosed, together with a wavelength monitor capable of detecting sidebands. A method is characterized by the usage of hot/cold parameter K which takes two values 0 and 1 indicating the cold and hot state of the device, respectively. The parameter K, which is reset to 0 at the start, is set to 1 when the laser beam is stabilized; it is reset to 0, whenever the lasing pause exceeds a predetermined time length. Preparatory starting steps are performed or omitted at the start, depending on the value of K. Another method is characterized by the adjustment of the intracavity etalons during the lasing pauses, in accordance with exponential functions with thermal time constants. The sideband detecting wavelength monitor comprises a single etalon whose free spectal region FSRm is selected with respect to that, FSR_2, of the fine tuning intracavity etalon in such a manner that the interference fringes of the sidebands formed by the monitor etalon are distinct from each other and from those of the central wavelength λ_0. Namely, when i is the integer which is associated with a sideband wavelength λ_S via the equation: $\lambda_S=\lambda_0+i\times FSR_2$, the free spectral regions FSR_2 and FSRm are selected in such a manner that the apparent wavelength differences: $R=i\cdot FSR_2+j\cdot FSRm$ between the central wavelength λ_0 and the sideband wavelengths λ_S, wherein j is an integer which minimizes the value of R for each i, are different from zero and from each other.

21 Claims, 15 Drawing Sheets



hrough th partial mirror 3 as a laser beam 6 at a pred t rmin d output lev l.

(7) In th as f an xcim r, semiconduct r, r dy las r, r c rtain kinds of solid state lasers, the oscillation frequency or wavelength width (i.e. bandwidth) of the laser generated by the medium 1 itself is relatively wide; as mentioned above, however, the bandwidth can be reduced by inserting spectral narrowing dispersive elements in the oscillator optical cavity. Thus, in the case of the device of FIG. 1, coarse and fine tuning etalons 4 and 5 are inserted in the cavity as spectral narrowing elements. The two etalons act essentially as band-pass filters. The fine tuning etalon 5 has high resolution (i.e. the width of the pass bands thereof is small) but includes a plurality of transmission peaks within the laser amplification band; the coarse tuning etalon 4 has a lower resolution and is used to select one of the transmission peaks of the fine tuning etalon 5. The detail of the spectral narrowing by the two etalons 4 and 5 is as follows.

(8) FIGS. 2(a) and 2(b) show the spectral characteristics of the optical elements of the laser device shown in FIG. 1. Namely, FIG. 2 (a) shows the transmission characteristics of the coarse tuning etalon 4, wherein the transmission (i.e. the ratio of the intensity of light transmitted through the etalon) of the etalon 4 is shown as a function of the wavelength .lambda. plotted along the abscissa; 2(b) shows the transmission characteristics of the fine tuning etalon 5 in the same manner; (c) shows the laser gain profile of the laser medium 1 as a function of the wavelength .lambda.; (d) shows the output spectral characteristics of the laser beam 6 which has undergone the spectral narrowing via the intracavity etalons 4 and 5.

(9) FIGS. 2(a) and 2(b), the wavelengths .lambda.m at the peaks of the transmission of the etalons 4 and 5 are given by:

(1) .lambda.m=2.multidot.n.multidot.d.multidot.cos.theta. /m, (1)

(10) wherein n is the re

US005144498A

United States Patent [19]

Vincent

[11] Patent Number: 5,144,498

[45] Date of Patent: Sep. 1, 1992

[54] VARIABLE WAVELENGTH LIGHT FILTER AND SENSOR SYSTEM

[75] Inventor: Kent D. Vincent, Cupertino, Calif.

[73] Assignee: Hewlett-Packard Company, Palo Alto, Calif.

[21] Appl. No.: 480,172

[22] Filed: Feb. 14, 1990

[51] Int. Cl.[5] G02B 5/20

[52] U.S. Cl. 359/885; 359/890; 359/722; 359/359; 250/226; 356/320

[58] Field of Search 359/885, 887, 890, 350, 359/359, 618, 722, 723; 356/300, 320, 331, 332, 51, 303, 346, 345, 328; 250/226

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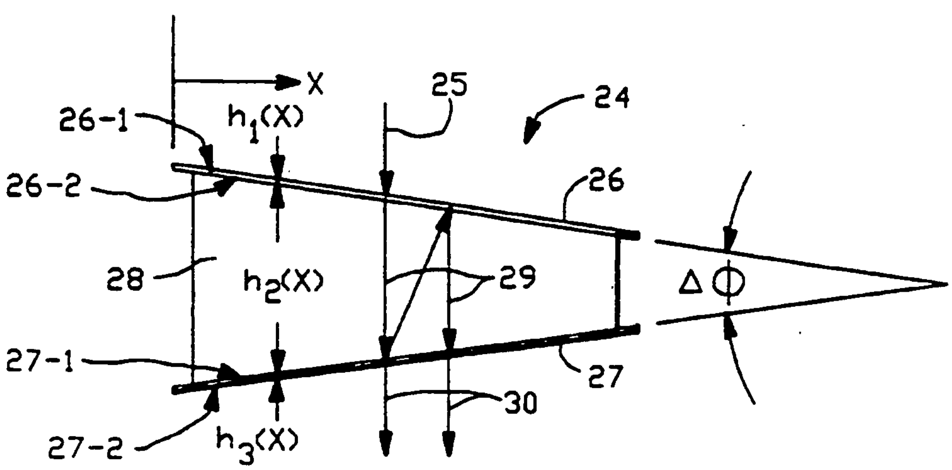
Primary Examiner—Loha Ben

[57] ABSTRACT

Light filter apparatus for receiving a light beam having wavelengths in a selected band and for dispersing the light into a plurality of rays, with each ray having a different wavelength for which the intensity peaks. The peak wavelength varies approximately continuously with displacement of spatial position in a chosen direction along the filter's light-receiving plane. In one embodiment, the filter is a modified etalon structure having at least two reflecting surfaces whose separation distance is not constant but increases or decreases monotonically with distance in a chosen direction in a light-receiving plane of the etalon. Each of these two reflecting surfaces may be planar or non-planar but continuous, or may have a step or staircase configuration. This structure may operate using transmitted light or reflected light. In a second embodiment, an edge filter combination is used to produce a narrow band of transmitted or reflected light having a variable central wavelength that varies with position along the chosen direction. In a third embodiment, a multi-layer thin film structure is used to provide a narrow band of transmitted or reflected light having a variable central wavelength. The filter may be combined with a one-dimensional or two-dimensional array of photosensor elements, which array may be linear, circular or generally curvilinear, one such element receiving a group of adjacent light rays of similar peak wavelength, to provide a plurality of different wavelength readings on an incident light beam for spectrophotometry or colorimetry analysis.

84 Claims, 15 Drawing Sheets



s from 7.25 cm for th low
r solution etal n 22 t 72.5 cm f r th high r s luti n talon 24. Th ptical paths for th r sp tiv etal ns ar fold d back and f rth b tw n mirrors, as sh wn, to accommodat th r latively long focal l ngths.

(23) Each of the etalons 22-24 comprises a realtively rigid thermally conductive housing 64, such as an elongated aluminum cylinder having a wall thickness of 1/2 inch and a diameter as of 2 inches. The etalon includes a pair of parallel partially transmissive planar mirrors 65 precisely spaced apart by the distance l. In a typical example the mirrors are formed by silver coatings placed upon fused silica cylindrical substrate members 66. The spacing l between the mirrors 65 is precisely determined by an annular fused silica spacer 67 ground to a precise axial length and provided with optically flat end surfaces for optically contacting the opposed surfaces of the fused silica mirrors 66. The fused silica spacer 67 has a slightly greater diameter than the fused silica mirrors 66 and the spacer 67 is bonded at its outer periphery to the inside wall of the cylindrical housing 64.

(24) Opposite ends of the cylindrical housing 64 are closed off via planar windows 68 retained onto the end of the cylinders via retaining rings 69 and the windows are sealed in a gas tight manner to the ends of the housing 64 via O-ring seals 71. The interior bore 72 of the housing 64 is evacuated to a relatively low pressure, as of a few torr, and filled with a gas such as argon
h

United States Patent [19]

Chraplyvy

[11] **4,241,997**

[45] **Dec. 30, 1980**

[54] **LASER SPECTROMETER WITH FREQUENCY CALIBRATION**

[75] Inventor: **Andrew R. Chraplyvy**, Troy, Mich.

[73] Assignee: **General Motors Corporation**, Detroit, Mich.

[21] Appl. No.: **968,352**

[22] Filed: **Dec. 11, 1978**

[51] **Int. Cl.**[3] **G01J 3/34**

[52] **U.S. Cl.** **356/309**; 356/323; 356/326; 356/243

[58] **Field of Search** 356/308, 309, 319, 320, 356/321, 323, 324, 325, 326, 328

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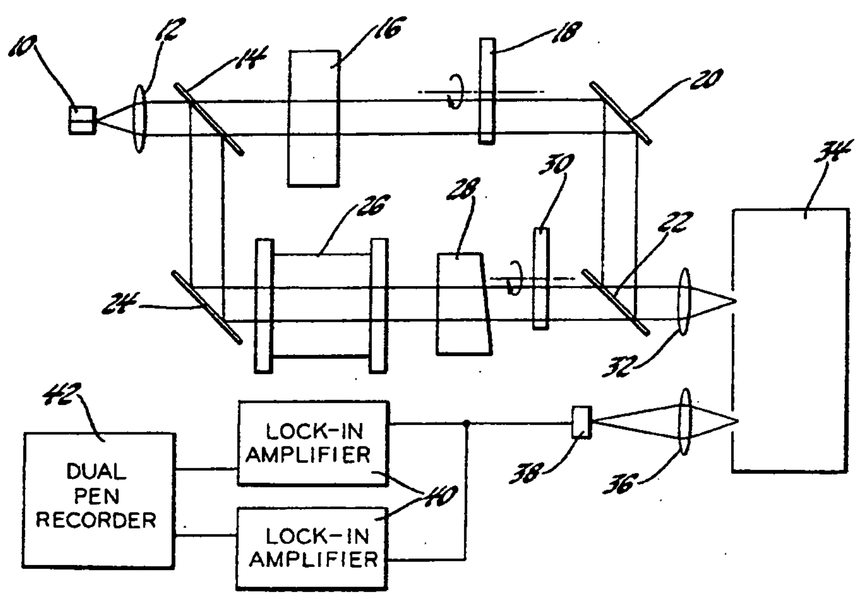
Primary Examiner—Vincent P. McGraw
Attorney, Agent, or Firm—Warren D. Hill

[57] **ABSTRACT**

A laser beam from a tunable laser is split into two paths containing an etalon and a sample cell respectively. The two paths are chopped at different frequencies. The paths are combined and fed to a monochromator and then detected by a single detector. Lock-in amplifiers tuned to the chopper frequencies and responsive to the detector output produce signals corresponding to the spectra arising from the etalon and the sample gas absorption. A recorder simultaneously displays the two spectra.

1 Claim, 2 Drawing Figures



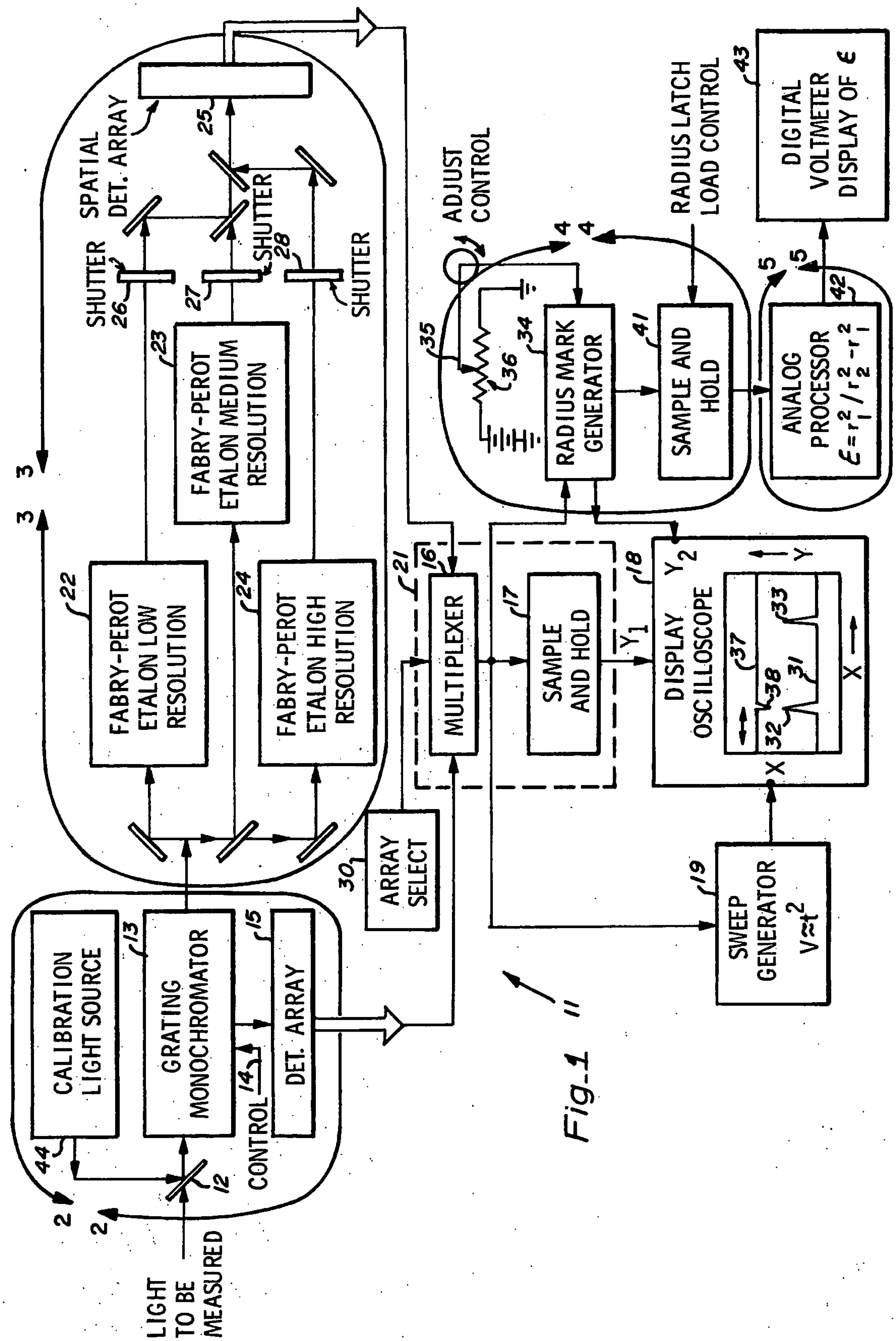
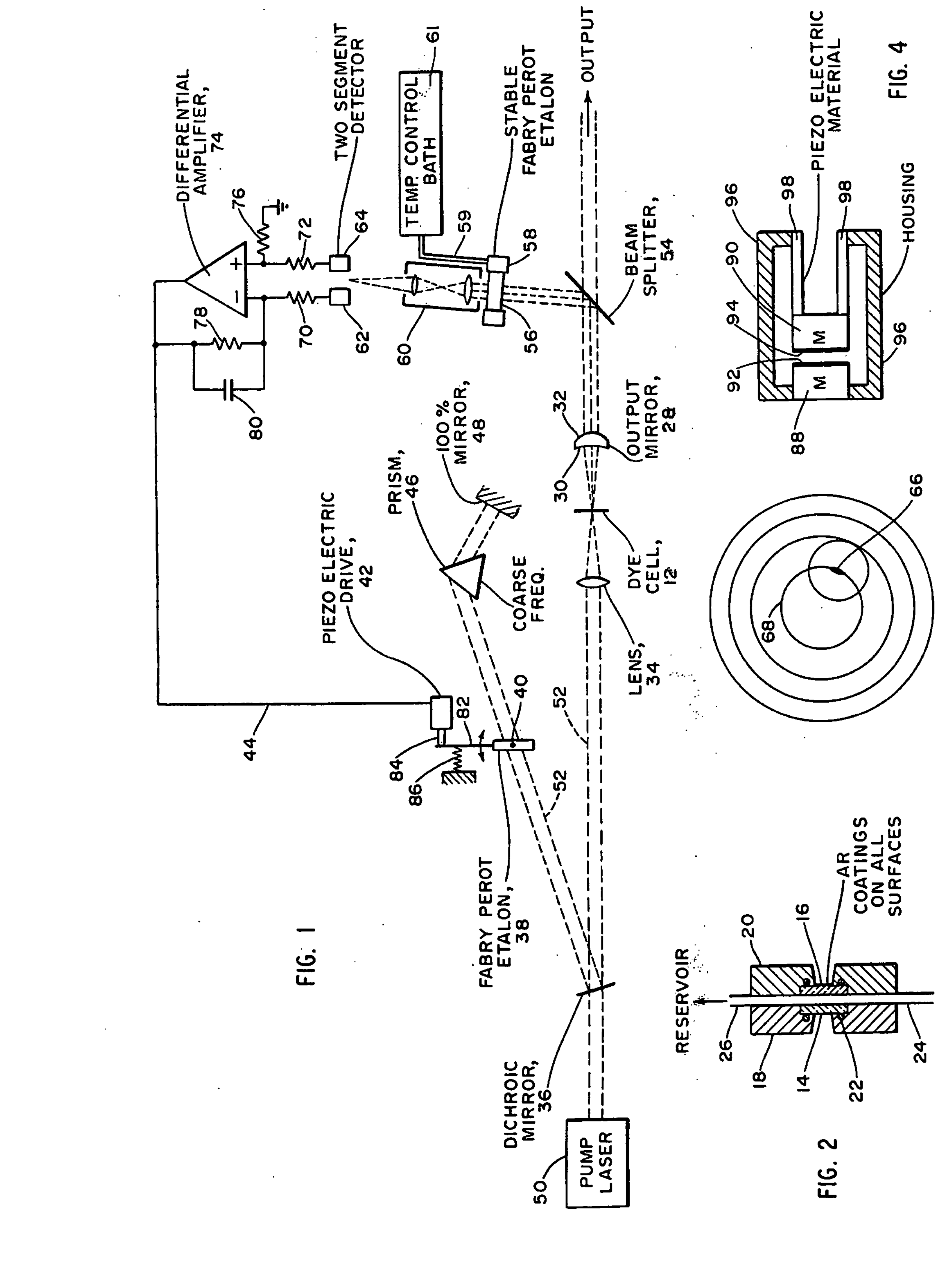

LIGHT TO BE MEASURED
CALIBRATION LIGHT SOURCE
GRATING MONOCHROMATOR
CONTROL
DET. ARRAY
ARRAY SELECT
FABRY-PEROT ETALON LOW RESOLUTION
FABRY-PEROT ETALON MEDIUM RESOLUTION
FABRY-PEROT ETALON HIGH RESOLUTION
SHUTTER
SHUTTER
SHUTTER
SPATIAL DET. ARRAY
MULTIPLEXER
SAMPLE AND HOLD
DISPLAY OSCILLOSCOPE
SWEEP GENERATOR V≈t²
ADJUST CONTROL
RADIUS MARK GENERATOR
SAMPLE AND HOLD
RADIUS LATCH LOAD CONTROL
ANALOG PROCESSOR ε=r₁²/r₂²-r₁²
DIGITAL VOLTMETER DISPLAY OF ε

Fig-1


DIFFERENTIAL AMPLIFIER, 74
TWO SEGMENT DETECTOR
TEMP. CONTROL BATH
61
STABLE FABRY PEROT ETALON
OUTPUT
76
72
64
59
58
78
70
62
60
56
80
BEAM SPLITTER, 54
32
OUTPUT MIRROR, 28
30
100% MIRROR, 48
PRISM, 46
PIEZO ELECTRIC DRIVE, 42
COARSE FREQ.
DYE CELL, 12
LENS, 34
44
82
40
52
84
86
FABRY PEROT ETALON, 38
FIG. 1
DICHROIC MIRROR, 36
PUMP LASER
50
FIG. 2
RESERVOIR
PUMP
AR COATINGS ON ALL SURFACES
20
16
26
18
14
22
24
FIG. 3
66
68
FIG. 4
PIEZO ELECTRIC MATERIAL
HOUSING
96
98
90
94
92
88
M